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A comparison of target detection and rifle marksmanship during live and simulator firing with and without caffeine consumption

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Defence R&D Canada – Toronto
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Abstract

This study compared the effects of caffeine ingestion on target detection and rifle marksmanship during live and simulated firing. Thirteen male, rifle-trained Canadian Forces (CF) reservists performed a total of 1 familiarization and 4 experimental sessions over an 8 day period. Familiarization was conducted on the small arms trainer (SAT), while the 4 experimental sessions were randomly and evenly distributed between 2 sessions of SAT and Automated Targetry System (ATS) live shooting. Each session was comprised of 8 shooting sequences one hour following the ingestion of 300 mg of caffeine or placebo. Shooting sequences included both friend-foe (FF) and vigilance (VIG) tasks and were performed in the following sequence: two FF engagements (4 minutes each), four VIG engagements (30 minutes each), and two FF engagements (4 minutes each). The shooting session lasted approximately 2.5 hours for both the caffeine and placebo trials. Performance measures during the shooting session included friend-foe discrimination, and marksmanship accuracy and precision. Assessments of thermal comfort and tiredness preceded and followed the shooting session. The Environmental Symptoms Questionnaire was administered pre- and post-shooting, while the Task Load Index was administered post-shooting only. Blood was sampled immediately prior to the beginning of the shooting session and was used to determine plasma caffeine levels. Caffeine resulted in lower subjective sensations of effort and an increased initial level of thirst. Subjects reported feeling colder on the ATS, and experienced blurred vision and lower levels on wakefulness on the SAT. Marksmanship performance was substantially poorer in the SAT and adversely affected by caffeine. No caffeine-induced performance decrements were noted on the ATS, but caffeine resulted in a greater number of shots taken on both the SAT and ATS. The results of this study indicate that although consistencies between live and simulator fire were not established, rectifying several key technological constraints would help realise the research potential of the SAT.

Résumé

Cette étude comparait les effets de l'ingestion de caféine sur la détection des cibles et l'adresse au tir, dans le cadre de tirs réels et simulés. Treize réservistes des Forces canadiennes (FC), de sexe masculin et entraînés au tir, se sont soumis à 1 séance de familiarisation ainsi qu'à 4 séances expérimentales, sur une période de 8 jours. La séance de familiarisation a eu lieu sur le simulateur d'entraînement au tir aux armes légères (SAT), tandis que les 4 séances expérimentales ont été réparties au hasard et également entre 2 séances sur le SAT et les séances de tir réel sur le système de ciblerie automatique (SCA). Chaque séance comportait 8 séquences de tir, exécutées une heure après l'ingestion de 300 g de caféine ou d'un placebo. Les séquences de tir comprenaient des tâches d'identification ami-ennemi (IFF) et des tâches de vigilance (V), et étaient exécutées dans l'ordre suivant : deux engagements IFF (4 minutes chacun), quatre engagements V (30 minutes chacun), et deux engagements IFF (4 minutes chacun). La séance de tir durait environ 2,5 heures, pour les essais avec caféine comme pour ceux avec placebo. Les indicateurs de performance utilisés durant les séances de tir étaient l'identification ami-ennemi et l'exactitude et la précision du tir. Ces séances de tir étaient précédées et suivies par une évaluation du confort thermique et de la fatigue ainsi que par l'administration du questionnaire sur les symptômes liés à l'environnement (Environmental Symptoms Questionnaire, ESQ); on calculait également l'indice de charge de travail (Task Load Index) à la fin des séances. Des échantillons de sang étaient prélevés immédiatement avant le début de la séance de tir pour déterminer les teneurs plasmatiques en caféine. La présence de caféine s'est traduite par une diminution des sensations d'effort subjectives et une hausse du degré de soif initial. Les sujets ont déclaré avoir eu plus froid lors des séances SCA, et avoir eu la vue brouillée et un niveau d'éveil moindre lors des séances SAT. La performance au tir a été nettement inférieure dans les séances SAT et a été perturbée par la caféine. On n'a observé aucune diminution de performance induite par la caféine dans les séances SCA, mais la présence de la substance s'est traduire par une augmentation du nombre de coups tirés dans les deux situations (SAT et SCA). Les résultats de cette étude indiquent que, malgré le manque d'uniformité entre les tirs réels et simulés, la correction de plusieurs problèmes techniques majeurs permettrait de réaliser le plein potentiel du SAT pour la recherche.

Executive summary

As part of a research program examining the effects of physiological stressors on target detection and rifle marksmanship (TD&M), an investigation into the effect of caffeine ingestion on TD&M was conducted on both a live-fire range as well as an advanced small arms trainer (SAT). Caffeine has been shown to increase both alertness [12] and improve physical work capacity [4]. Consequently, it has been proposed to be of potential benefit to soldier performance. For example, caffeine has also been shown to improve both vigilance and friend/foe discrimination tasks without adversely affecting marksmanship [12; 13]. These studies were conducted using the Weaponeer simulator, and have not been verified in live-fire conditions or on other marksmanship simulators. In response to these questions, a study was conducted to determine the effect of caffeine consumption on TD&M during live-fire, and if the SAT could be used as a convenient, cost-effective facility for conducting marksmanship research. While the effect of caffeine alone on TD&M during live-fire is addressed in a concurrent paper [3], this report examines the validity and limitations of performing marksmanship studies in the SAT as compared to a live-fire range.

Thirteen rifle-trained military reservists from the 41 Canadian Brigade Group volunteered to participate in this study. Experimental sessions were conducted on the Automated Targetry System (ATS) and the SAT (FATS IV, FATS Inc., Suwanne GA) ranges at CFB Edmonton, supported by members of the ASU Edmonton Training Support Company. Each subject underwent one familiarization session on the SAT, followed by 4 experimental sessions over an 8-day period. Two of these sessions were conducted on the ATS range, while the other two were conducted on the SAT. Each session consisted of the ingestion of two gelatin capsules containing either 300 mg of caffeine or a placebo, approximately 1 hour prior to shooting. Caffeine/placebo administration was randomized and blinded to the subject and range staff. All weapon firing was done using a standard or SAT modified C7A1 rifle with C79 scope. Targets were presented in two friend/foe (FF) sequences of 4 minutes each, two vigilance (VIG) sequences of 1 hour each, followed by an additional two FF sequences for a total session time of approximately 2.5 h. All targets consisted of standard or modified, figure E targets at a range of 200 m. Targets were modified in the FF condition only, and consisted of a black and white diagonal striping pattern which direction was used to differentiate friendly from foe targets. Blood samples were taken prior to shooting to determine plasma caffeine levels, and subjective rating questionnaires were administered prior to and upon completion of the sessions. Marksmanship was evaluated for precision and accuracy of shot location. All subjects underwent the same session conditions and shooting sequences in a randomized but counterbalanced order.

Subjective questionnaires revealed a decrease in perceived exertion with caffeine on both ATS and SAT ranges, while overall cold sensation was greater on the ATS. This was not surprising as the ambient temperature of the ATS range was cooler than the SAT. Subjects reported cold hands and feet on the ATS, while blurry vision and a decreased wakefulness were experienced on the SAT. Individuals also perceived their performance to be lower on the SAT. Caffeine resulted in a greater initial level of thirst and decreasing levels of tiredness over the duration of an experimental session. In contrast, tiredness increased with time in the placebo condition.

Analysis of the FF data demonstrated that the subjects were reasonably able to discriminate between the friendly and foe targets. When comparing appropriate (e.g. firing at foes or holding fire on friendly targets) and inappropriate responses, more inappropriate responses were made on the SAT. Most errors were made during the first FF sequence, and there was no difference in the subsequent sequences. SAT performance was worse that ATS with respect to number of targets hit. Only 54% of SAT targets engaged were hit, while 87% of ATS targets found their mark. Again, the poorest performance occurred in the initial sequence.

As with FF, fewer targets were hit on the ATS range during VIG, and the targets hit to shots ratio was also lower. Caffeine consumption resulted in subjects increasing the number of shots taken during a sequence. Shot location data generated in the SAT were deemed to be of poor quality and susceptible to technological deficiencies. As a result only data from 4 subjects were useable. From this limited data set, it was apparent that marksmanship accuracy and precision were significantly worse in the SAT. Caffeine did not influence any marksmanship measures in the ATS, but decreased performance in the SAT.

The results of this study indicate marksmanship performance in the SAT is markedly different from live-fire resulting in poorer performance in almost every index measured. Although previous researchers were able derive simple correlations between live and simulated shooting scores, the failure to reproduce the effects of a stressor (caffeine) between the two ranges suggest that the scope of conformity between live and simulator fire may be limited.

Much of the difference between the ranges may be attributed to the ambient environment in which they are situated, subjective biases against the simulator, poor projected image quality, and technical deficiencies of the SAT. A major technological concern centered on the fact that the system software occasionally failed to register the zeroing information of a weapon at the beginning of a target sequence. Consequently, shot location would have been biased by an unknown factor. As a result, it is highly probable that the quality of performance measures was adversely affected. Additionally, as the SAT was designed to be a training system, the data reporting capability was limited and tedious to extract. This resulted in either a failure to capture data due to time constraints, or a substantial interruption to the continuity of an experimental session.

http://corpranet.toronto.drdc-rddc.gc.ca/corpranet/services/imag_photo/guide_tips/tips.htmA comparison of SAT and live-fire marksmanship, with and without caffeine consumption, revealed significant differences in subjective perceptions and shooting performance. Many of these differences may be attributed to the ambient environment in which they are situated and the known technological deficiencies of the SAT. While field environmental conditions are difficult to control, it is doubtful that they had as great an impact on performance as the technical problems of the SAT. With the subsequent delivery of a new generation of SATs, visual acuity has been markedly improved, and the zeroing issue addressed. These system improvements, coupled with an enhanced data reporting capability and the development of a SAT facility which provides a similar level of arousal as a live range should enable the SAT to realize its potential as a cost-effective and flexible marksmanship research platform.

Keefe, A.A., Tikuisis, P. 2003. A comparison of target detection and rifle marksmanship during live and simulator firing with and without caffeine consumption. DRDC Toronto TR 2003-003. Defence R&D Canada – Toronto.

Sommaire

Dans le cadre d'un programme de recherche portant sur les effets des facteurs de stress physiologiques sur la détection des cibles et l'adresse au tir, une étude sur l'effet de l'ingestion de caféine a été réalisée sur un champ de tir réel ainsi que sur un simulateur avancé d'entraînement au tir aux armes légères (Small Arms Trainer, SAT). Il est apparu que la caféine augmentait à la fois la vivacité d'esprit [12] et la capacité de travail physique [4], ce qui donne à penser que la caféine pourrait éventuellement avoir un effet bénéfique sur la performance des soldats. Il est également apparu que la caféine améliorait la vigilance et l'identification ami-ennemi, sans nuire à l'adresse au tir [12; 13]. Ces études ont été réalisées à l'aide du simulateur Weaponeer, et n'ont pas été vérifiées en conditions de tir réel ou sur d'autres simulateurs de tir. En conséquence, une étude a été effectuée pour évaluer l'effet de la consommation de caféine sur la détection des cibles et l'adresse au tir en conditions de tir réel, et pour savoir si le SAT pouvait servir d'installation commode et économique pour les recherches sur l'adresse au tir. L'effet de la caféine seule sur la détection des cibles et l'adresse au tir en conditions de tir réel fait l'objet d'un article publié simultanément [3]; nous nous penchons ici sur la validité et les limites des études sur l'adresse au tir réalisées au moyen du SAT, par rapport aux études menées dans un champ de tir réel

Treize réservistes entraînés au tir du 41e Groupe-brigade du Canada se sont portés volontaires pour cette étude. Des séances expérimentales ont été organisées sur le système de ciblerie automatique (SCA) et le simulateur de tir aux armes légères (SAT, FATS IV, FATS Inc., Suwanne GA) à la BFC d'Edmonton, avec l'appui des membres de la compagnie de soutien à l'instruction de l'USS Edmonton. Après une séance de familiarisation sur SAT, chaque sujet a été soumis à 4 séances expérimentales sur une période de 8 jours. Deux de ces séances ont eu lieu sur le champ de tir SCA, et les deux autres sur le SAT. À chaque séance, les sujets ingéraient deux gélules de gélatine contenant soit 300 mg de caféine, soit un placebo, environ 1 heures avant la séquence de tir. L'administration de la caféine ou du placebo se faisait au hasard et à l'insu des sujets et du personnel du champ de tir. Tous les tirs ont été exécutés à l'aide de fusils C7A1 modifiés, avec lunette de visée C79. Les cibles étaient présentées dans le cadre de deux séquences d'identification ami-ennemi (IFF) de 4 minutes chacune et de deux séquences de vigilance (V) d'une heure chacune, suivies de deux nouvelles séquences IFF, pour une séance d'une durée totale d'environ 2,5 heures. Toutes les cibles consistaient en cibles-silhouettes E standard ou modifiées, à une distance de 200 m. Les cibles n'étaient modifiées qu'en condition IFF, et consistaient en une surface noir et blanc rayée en diagonale, dont la direction servait à différencier la nature (ami ou ennemi). Des échantillons de sang ont été prélevés avant chaque tir afin de déterminer la teneur plasmatique en caféine; les sujets devaient en outre répondre à un questionnaire d'appréciation subjective avant et après les séances. L'adresse au tir était évaluée sur le plan de la précision et de l'exactitude du tir. Tous les sujets ont été soumis aux mêmes conditions et aux mêmes séquences de tir dans un ordre aléatoire, mais équilibré.

Les questionnaires d'appréciation subjective ont mis en évidence une diminution de la fatigue perçue chez les sujets qui avaient pris de la caféine, sur le champ de tir SCA et sur le SAT, ainsi qu'une sensation générale de froid accrue dans le champ de tir SCA. Ce dernier résultat n'est guère étonnant étant que la température ambiante du champ de tir SCA était

effectivement plus basse que sur le SAT. Les sujets ont déclaré avoir eu froid aux mains et aux pieds sur le champ de tir SCA, et avoir eu la vue brouillée et un niveau d'éveil moindre sur le SAT. Les sujets ayant ingéré de la caféine ont déclaré un degré de soif initial plus prononcé et une fatigue moindre sur la durée d'une séance expérimentale, alors que chez les sujets ayant absorbé un placebo, la fatigue a augmenté avec le temps.

L'analyse des données IFF a révélé que les sujets étaient raisonnablement en mesure de distinguer entre les deux types de cibles. Pour ce qui est de la comparaison des réponses correctes (p. ex. tirer sur les cibles ennemies et retenir le tir sur les cibles amies) et incorrectes, le nombre de réponses incorrectes était plus élevé sur le SAT. La majorité des erreurs ont été commises durant la première séquence IFF; on n'a plus observé de différence lors des séquences suivantes. En ce qui concerne le nombre de cibles touchées, la performance était moins bonne sur le SAT que sur le champ de tir SCA. Seulement 54 % des cibles présentées sur le SAT ont été touchées, contre 87 % des cibles SCA. Encore une fois, la mauvaise performance a été observée lors de la séquence initiale.

Comme dans les séquences IFF, le nombre de cibles touchées lors des séquences SCA a été moins élevé dans les tâches de vigilance, et le rapport entre les coups au but et les coups tirés a également été plus faible. Les sujets qui avaient ingéré de la caféine ont tiré plus souvent pendant les séquences. Les données sur les points d'impact produites par le SAT ont été jugées de mauvaise qualité et sensibles aux déficiences technologiques, si bien qu'on n'a pu utiliser que les données de 4 sujets. À partir de cet ensemble limité de données, il est apparu que l'exactitude et la précision des tirs étaient de loin inférieures dans les séances SAT. La caféine n'a eu par ailleurs aucune incidence sur les indicateurs de l'adresse au tir en situation SCA, mais a abaissé la performance sur le SAT.

Les résultats de cette étude révèlent que la performance au tir sur le SAT diffère beaucoup de celle observée en conditions de tir réel, ce qui se traduit par une moins bonne performance pour presque tous les indices mesurées. Bien que des chercheurs aient déjà réussi à dériver des corrélations simples entre les scores de tir en conditions réelles et en conditions simulées, le défaut de reproduire les effets d'un facteur de stress (la caféine) entre les deux champs de tir donne à penser que l'ampleur de la conformité entre le tir réel et simulé pourrait être limitée.

La différence entre les champs de tir peut en grande partie être attribuée au milieu ambiant dans lequel ils se trouvent, aux préjugés défavorables à l'égard du simulateur, à la mauvaise qualité des images projetées et aux déficiences techniques du SAT. Un problème technique important venait de ce que le logiciel du système omettait parfois d'enregistrer les informations sur le zérotage d'une arme au début d'une séquence de cible. En conséquence, les données sur le point d'impact ont sans doute été biaisées par un facteur inconnu. Il est donc fort probable que cela ait eu une incidence négative sur la qualité des indicateurs de performance. En outre, comme le SAT a été conçu comme un système d'entraînement, sa capacité de communiquer des données était limitée et les données étaient pénibles à extraire, ce qui s'est traduit soit par le défaut d'extraire les données à cause des contraintes temporelles, soit par une interruption importante dans la continuité d'une séance expérimentale.

Une comparaison de l'adresse au tir sur le SAT et en conditions réelles, avec et sans consommation de caféine, a mis en évidence d'importantes différences dans les perceptions subjectives et la performance du tir. Nombre de ces différences pourraient être attribuables au

milieu ambiant dans lequel ont lieu les séances et aux déficiences techniques connues du SAT. Bien que les conditions ambiantes du champ de tir soient difficiles à contrôler, on peut douter qu'elles aient eu autant d'impact sur la performance que les problèmes techniques du SAT. La prochaine génération de simulateurs SAT offre une acuité visuelle nettement supérieure, et le problème du zerotage a été résolu. Ces améliorations, alliées à une meilleure capacité de communication des données et au développement d'une installation SAT procurant un degré de stimulation semblable à celui d'un champ de tir réel, devraient permettre au SAT de réaliser son plein potentiel comme plate-forme souple et économique pour la recherche sur l'adresse au tir.

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Introduction

Simulators are increasingly being used as a complement/surrogate to live fire practice for training soldiers in small arms handling and marksmanship. Simulators provide the benefit of an increasingly realistic shooting experience in a safe, controlled, and cost effective manner. A variety of training scenarios can be quickly authored and immediate performance feedback is provided to the soldier. In more sophisticated systems, detailed information regarding aim point, weapon status, and handling may also be reported.

Although the benefits of marksmanship simulators appear to be self evident, the transfer of skills learned in the simulator to live-fire applications requires validation. Studies addressing this issue have investigated the Weaponeer [16], Engagement Skills Trainer [6], Multipurpose Arcade Combat Simulator [19], and Small Arms Trainer (SAT) [1; 2; 5] systems. These validation studies have focused on the comparison of scores on standardized weapon qualification tasks normally conducted on a live-fire range. In general, these studies have found a positive correlation between live and simulated firing performance with a large variation of training effect within the sample population. For example, White [19] found that those with poor marksmanship ability benefited the most from simulator training, while the average and highly skilled trainee did not benefit. Also, simulator performance scores relative to live fire tend to worsen with increasing distance. Gula [5] found simulator scores to be higher at a target distance of 100 m, while live-fire scores were better at 200 m. It was hypothesized that poor resolution of the projected images and inadequate or inappropriate perceptual cues may cause greater difficulty in the judgement of distances of the simulator targets. This suggests a possible limitation to the validity of the use of training simulator engagements authored across a wide range of target distances.

Recently, researchers have used simulators in an effort to quantify the effect of physiological and psychological stressors and/or ergogenic aids on marksmanship. The Weaponeer training simulator has been utilized in the investigation of the effect of numerous stressors/aids such as heat stress [8], protective clothing [10], prolonged vigilance [11], and caffeine [12; 13; 14] on target detection and marksmanship (TD&M). Tikuisis et al. [18] investigated the effect of heat and cold strain on TD&M using the SAT. These studies employed novel engagements involving extended periods of vigilance, friend/foe identification, and moving targets. Whether the live fire/simulator relationships determined in earlier studies apply to these new engagements has yet to be determined. Adding to the complexity of this research is the confounding aspect of unique target engagement that different simulator technologies present. There has not been, to our knowledge, a cross validation study comparing the effects of stressors/aids between various simulators.

In order to validate marksmanship simulators as surrogate research platforms in which to determine the scope of their applicability, a significant relationship between the performance of live and simulated fire must be established across a variety of target engagements. In addition, any effect due to stressors or aids on live marksmanship performance must be reproducible in the simulator in a consistent and predictable manner.

In an effort to investigate these relationships, a study was devised to compare TD&M performance of live and simulated fire during engagements involving friend/foe discrimination and vigilance. The SAT was the simulator selected, as it is the primary rifle-training simulator of the Canadian Forces (CF). Participants were given either a placebo or caffeine (300 mg) in both live and simulator conditions. Caffeine has been demonstrated to improve target detection time,

while not affecting marksmanship [14]. Based on previous literature and experience, it was hypothesized that TD&M performance would be similar in both live and simulated engagements, and that the performance enhancing effects of caffeine would be present in both conditions in a predictable and consistent manner.

Methodology

Subjects

Thirteen rifle-trained military reservists (age range and mean ± SD: 18 – 49 and 28 ± 9 yr) belonging to units within the 41 Canadian Brigade Group, Edmonton, volunteered to participate in this study. Subjects underwent a medical screening and anthropometric measurements (height: 170 – 188 and 179.1 ± 4.8 cm; weight: 68 – 114 and 83.1 ± 4.8 kg), and were given a full explanation of all risks, procedures, and benefits prior to giving their informed consent in accordance with protocol approval requirements from the DRDC Toronto Human Research Ethics Committee.

Subjects were asked to refrain from caffeine (eg., coffee, caffeinated tea and/or soft drinks, chocolate bars) and exercise for 12 h, and abstain from alcohol for 24 h prior to arrival for a trial. Aside from these exceptions, subjects were asked to conduct their normal daily routine during the entire experiment. A questionnaire was administered to provide an estimate of the subject's normal daily caffeine and nicotine intake. Tobacco users were permitted to chew, but not smoke, during the trials. Potential subjects were screened regarding the use of any medication, over the counter cold remedies, or antidepressants that may have precluded their participation.

Experimental trials

Subjects underwent one familiarization session, followed by 4 experimental sessions over an 8-day period. Since all subjects were familiar with live-fire procedures, the familiarization session was only conducted on the SAT (FATS IV, FATS Inc., Suwanee, GA). This session consisted of the ingestion of 300 mg of caffeine and approximately 2.5 h of rifle shooting at target scenarios identical to those that would be experienced in the experimental sessions.

Two of the experimental sessions consisted of live-fire engagements held on the Automated Targetry System (ATS) range (ATA Defence Industries, Camden, TN), while the other two were conducted on the SAT, both located at CFB Edmonton. In each session, subjects were given gelatine capsules containing either a placebo (P) or 300 mg caffeine, hereafter denoted as the drug (D), approximately 1 h prior to shooting. All sessions consisted of firing a standard or SAT-modified C7A1 rifle, equipped with a C79 scope at pop-up targets at a range of 200 m. The SAT rifle is modified with the addition of weapon function sensors, a laser device in the barrel, and a compressed air hose connected to the forestock. Targets were presented in two friend/foe (FF) sequences of 4 min each, two vigilance (VIG) sequences of 1 h each, followed by two more FF sequences for a total session time of approximately 2.5 h. Subjective ratings questionnaires were administered prior to and upon completion of the shooting sessions. All subjects underwent the same session conditions and shooting sequences in a randomized but counterbalanced order. Figure 1 gives an overview of an experimental session.

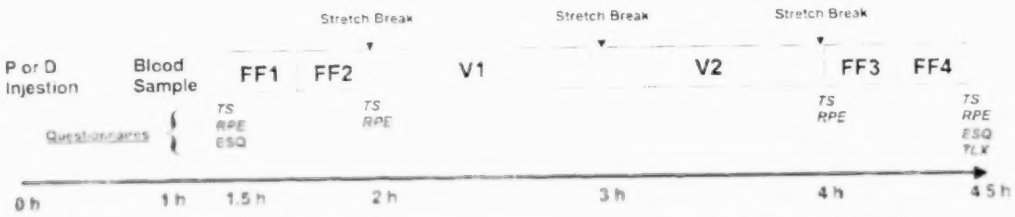

Figure 1. *Timeline of each experimental session, see text for explanation of abbreviations*

Trial randomization

Subjects were randomly assigned to participate in either a morning (A) or afternoon (B) group. Group A conducted their activities between 0700h and 1200h, and group B between 1300h and 1800h. Within these groups, subjects were further randomized such that on each trial day, one half would conduct live fire (L) on the ATS range while the other half would be engaged with simulated fire (S) on the SAT.

Each group was counterbalanced with respect to drug vs. placebo, live vs. simulated fire, and shooting sequences. Four different but equally difficult shooting sequences (a to d) were implemented for both FF and VIG engagements. Ideally, 16 subjects were required to complete the balanced design. As only 15 subjects were available to participate in the study and two of these from the morning group withdrew during the course of the study, an imbalance in the experimental design was unavoidable. Table 1 details the resultant randomization matrix and its implementation.

Table 1. *Randomization of trials where A and B refer to the am and pm groups, and D and P refer to the drug and placebo, respectively. The hatched and grey rows indicate subject dropout, and incomplete design, respectively. The lowercase letters indicate shooting sequence*

SUBJECT	TRIAL			
	I	*II*	*III*	*IV*
A1	D/ATS a	P/ATS b	D/SAT c	P/SAT d
A2	D/ATS b	P/SAT c	D/SAT d	P/ATS a
A3	P/ATS c	D/SAT d	P/SAT a	D/ATS b
A4	P/ATS d	D/ATS a	P/SAT b	D/SAT c
A5	D/SAT a	P/SAT b	D/ATS c	P/ATS d
A6	D/SAT b	P/ATS c	D/ATS d	P/SAT a
A7	P/SAT c	D/ATS d	P/ATS a	D/SAT b
A8	P/SAT d	D/SAT a	P/ATS b	D/ATS c
B1	D/ATS c	P/ATS d	D/SAT a	P/SAT b
B2	D/ATS d	P/SAT a	D/SAT b	P/ATS c
B3	P/ATS a	D/SAT b	P/SAT c	D/ATS d

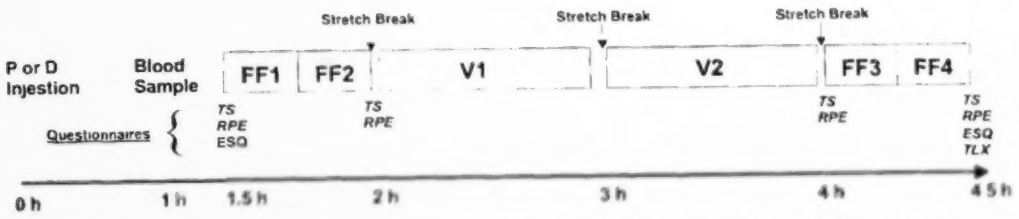

Figure 1. *Timeline of each experimental session, see text for explanation of abbreviations*

Trial randomization

Subjects were randomly assigned to participate in either a morning (A) or afternoon (B) group. Group A conducted their activities between 0700h and 1200h, and group B between 1300h and 1800h. Within these groups, subjects were further randomized such that on each trial day, one half would conduct live fire (L) on the ATS range while the other half would be engaged with simulated fire (S) on the SAT.

Each group was counterbalanced with respect to drug vs. placebo, live vs. simulated fire, and shooting sequences. Four different but equally difficult shooting sequences (a to d) were implemented for both FF and VIG engagements. Ideally, 16 subjects were required to complete the balanced design. As only 15 subjects were available to participate in the study and two of these from the morning group withdrew during the course of the study, an imbalance in the experimental design was unavoidable. Table 1 details the resultant randomization matrix and its implementation.

Table 1. *Randomization of trials where A and B refer to the am and pm groups, and D and P refer to the drug and placebo, respectively. The hatched and grey rows indicate subject dropout, and incomplete design, respectively. The lowercase letters indicate shooting sequence*

SUBJECT	TRIAL			
	I	*II*	*III*	*IV*
A1	D/ATS a	P/ATS b	D/SAT c	P/SAT d
A2	D/ATS b	P/SAT c	D/SAT d	P/ATS a
A3	P/ATS c	D/SAT d	P/SAT a	D/ATS b
A4	P/ATS d	D/ATS a	P/SAT b	D/SAT c
A5	D/SAT a	P/SAT b	D/ATS c	P/ATS d
A6	D/SAT b	P/ATS c	D/ATS d	P/SAT a
A7	P/SAT c	D/ATS d	P/ATS a	D/SAT b
A8	P/SAT d	D/SAT a	P/ATS b	D/ATS c
B1	D/ATS c	P/ATS d	D/SAT a	P/SAT b
B2	D/ATS d	P/SAT a	D/SAT b	P/ATS c
B3	P/ATS a	D/SAT b	P/SAT c	D/ATS d

B4	P/ATS b	D/ATS c	P/SAT d	D/SAT a
B5	D/SAT c	P/SAT d	D/ATS a	P/ATS b
B6	D/SAT d	P/ATS a	D/ATS b	P/SAT c
B7	P/SAT a	D/ATS b	P/ATS c	D/SAT d
B8	P/SAT b	D/SAT c	P/ATS d	D/ATS a

Drug ingestion

Each trial began with the ingestion of two gelatin capsules containing either a placebo (Metamucil ®) or 300 mg of caffeine, and given a light snack consisting of a muffin and 300 mL of fruit juice. The fixed dose of caffeine resulted in a range from 4.4 to 2.6 $mg \cdot kg^{-1}$ depending on the subject's body mass, and is equivalent to the amount consumed in 2 to 4 cups of regular coffee.

Blood sampling

Approximately 1 h after capsule ingestion, a 3 ml sample of venous blood was taken from a vein in the subject's non-dominant forearm. Blood plasma from the sample was immediately separated and frozen for subsequent analyses of caffeine, testosterone as a possible correlate to target discrimination, and cortisol as a stress indicator. Subjects reported to their designated firing ranges immediately after the blood draw.

Shooting sessions

All ATS shooting sessions were conducted using a standard C7A1 assault rifle equipped with a C79 optical scope. The SAT uses a modified C7A1 that is actuated by compressed gas to provide realistic recoil and synchronized with an amplified speaker system to simulate the rifle crack.

Both the ATS and SAT ranges are computer controlled, allowing precise target appearance and disappearance scheduling, as well as detection of horizontal-vertical (x-y) shot location. Whereas the ATS is an outdoor live-fire range employing pneumatically lifted targets and an acoustic sensor array for shot detection, the SAT simulates the firing range by projecting its image onto a 2.3 x 3.1 m (7.5 x 10.0 ft) projector screen, and presenting target images at programmable times and locations. Firing of the SAT rifle results in laser light being emitted from the rifle barrel, and its screen splash location recorded by a hit detection camera for determination of shot co-ordinates relative to the target center of mass.

Both FF and VIG sequences were duplicated in the ATS and SAT using a modified 'Figure E Silhouette' (Cat. No 110-066, ATA Defense Industries, Camden, TN) pop-up targets at a range of 200 m. The orientation of a square-wave grating pattern (black and white stripes) was used to discriminate between friendly and foe targets (Figure 2). In each case, targets were up for 4 s and programmed not to fall if hit. Due to the pneumatic lifting arm of the ATS, targets took approximately 1.4 s to rise in an arc from hidden horizontal to the fully vertical position, whereas SAT targets appeared instantaneously. Subjects were instructed to engage only foe targets with

single well-placed shots and they were assigned non-contiguous lanes to prevent possible feedback or interference from others firing in parallel lanes.

Figure 2. *Modified 'Figure E Silhouette' target with friendly (a) and foe (b) patterns*

Friend/Foe discrimination

During each of the four 4-min FF sequences, 40 targets (25 foe and 15 friendly) were programmed to appear at random intervals. A total of four different FF sequences were authored and presented to all subjects in a counterbalanced order across the entire study. Subjects were instructed to engage only foe targets and hold their fire when a friendly target appeared. After each sequence, subjects were allowed a short stretch break during shot scoring and system reset.

Vigilance

The vigilance task involved 60 randomly appearing foe targets over a period of two hours. Targets were randomized within four 30-min sequences of 15 targets each. Due to limitations of the number of targets that could be programmed in the SAT and ATS, this task consisted of two 1-h engagements interrupted only with a brief stretch break to allow data downloading and system reset. As the SAT has no data downloading capabilities, shot location had to be recorded manually by cycling through each shot and transcribing x-y coordinates from the computer screen. This process required approximately 30 min, during which the subjects were permitted to wait in an adjoining hallway.

Questionnaires

Immediately prior to and following the shooting session, subjects were asked to provide subjective ratings of Perceived Exertion (RPE) and Thermal Sensation (TS). The Environmental Systems Questionnaire (ESQ) was completed at the beginning and end of the experimental session, and the Task Load Index (TLX) at the session's conclusion.

The ESQ [18] was developed to assess symptoms experienced by soldiers exposed to environmental extremes, and has been extended to provide an indication of general subjective perceptions of physiological and cognitive strain. The ESQ comprises 68 questions that are scored on a rank order basis ranging from 0 (symptoms not present) to 5 (extreme). Certain of these questions may be grouped to give additional sub-indices of cold discomfort, muscle discomfort, tiredness, and well-being.

The TLX [7] is a subjective workload assessment tool developed by the National Aeronautics and Space Administration (NASA) to evaluate mental, physical, and temporal demands, performance, effort, and frustration. Subjects marked their ratings on a horizontal line that represented, from left to right, perceptions of low to high subjective workload, or in the case of performance, from

good to poor. The mark on the line was scored linearly as a percentage of the length of the total line.

Analyses

Target detection was measured during each 4-min FF sequence and was based on the number of shots taken at foe targets and shots withheld at friendly targets. The calculated measures included the shot-hit ratio and discriminatory index (d'). d' provides a measure of discrimination sensitivity between two similar alternatives, and is based on signal detection theory [15] using the following equation:

$$d' = Z(\text{False Alarm Rate}) - Z(\text{Hit Rate}) \qquad \text{(Eq. 1)}$$

where

False Alarm Rate (Noise) = Proportion of friendly targets engaged,

Hit Rate (Signal + Noise) = Proportion of foe targets engaged,

and Z represents the location on a normal curve that divides the area under the curve into two parts, depicting the hits and misses, or false alarms and correct rejections. By superimposing the False Alarm Rate and Hit Rate distribution curves (normal distributions are assumed), and aligning the calculated Z scores, the difference between the peaks of each curve is the value d'. A value greater than or equal to 1.0 indicates that the subject was able to reasonably discriminate the friendly and foe targets.

Target engagement time (ET) was obtained only during ATS engagements using video and auditory analyses. A digital video camera (Model DCR-TRV315, Sony Corp., Japan) was placed adjacent to lane 1 and recorded target appearance and rifle shots at 30 fps. Only two participants were on the live range during FF engagements, allowing rifle recoil and exhaust to be clearly visible on the videotape. Frame-by-frame analysis was used to determine the precise moment of target appearance and rifle firing. Since up to 4 participants would be on the range during VIG engagements, the limited field of view of the camera made it impossible to view all participants adequately. As a result, shot time was determined through the analysis of the audio waveform, which revealed an obvious spike due to the rifle crack. Speed of sound delay was corrected according to the distance of the participants from the camera and ambient temperature using the following equation:

$$t_{shot} = t_{video} - \frac{d_{lane}}{331.4 + 0.6 \cdot T_A} \qquad \text{(Eq. 2)}$$

where

t_{shot} = true time of rifle shot (s),
t_{video} = time of rifle crack, as determined by audiovisual analysis (s),
d_{lane} = distance from camera to marksman (m), and
T_A = ambient temperature (°C).

Marksmanship performance was based on shot accuracy (distance relative to the target's centre of mass) and precision (shot group tightness). Accuracy was measured by the constant error [CE – distance between the centre of impact (CI) and the target centre of mass (CM)] and the shooting error (SE, defined by the average distance of each shot from CM). Precision was measured

according to the mean shot radius (MR, defined by the average of the straight line distance between each shot and CI), and the area (AREA) and diagonal (DIA) of the shot group dispersion. All measures of accuracy and precision were adopted from Johnson [9] and applied to both FF and VIG in the ATS, and during VIG in the SAT. Due to time limitations, these data were not recorded during SAT FF sequences. Marksmanship data were summarized for each 4 min FF sequence and each 30 min of VIG.

All target engagement and marksmanship scores, TS, RPE, and ESQ data were analyzed using a 3-way [Range (2) x Drug (2) x Time (2 or 4)] analysis of variance (ANOVA), while the TLX data were analyzed by a 2-way [Range (2) x Drug (2)] ANOVA. The Neuman-Keuls post-hoc test was employed where significant main effects were found ($p < .05$). All statistical analyses were completed using Statistica© software (Statsoft Inc., Tulsa, OK). Unless otherwise stated, all results are reported as mean $\pm$ SD.

Results

Blood Analysis

Blood samples were obtained for all subjects. As anticipated, plasma caffeine levels were higher during the drug trial (2098 ± 1908 $ng \cdot ml^{-1}$) vs. the placebo trial (550 ± 710 $ng \cdot ml^{-1}$) ($p < .01$). There were no differences in cortisol (11.55 ± 5.24 vs. 10.75 ± 4.56 µg/dL) and in total testosterone (4.10 ± 0.86 vs. 4.00 ± 0.94 ng/mL) levels between the ATS and SAT ranges, respectively

Questionnaires

RPE and TS

Complete data were available for 11 subjects for the RPE and TS questionnaires with results shown in Figure 3 and 4. There was a main effect of caffeine such that lower RPE scores, indicating less perceived effort, were noted in both the ATS and SAT ranges, compared to the placebo condition ($p < .05$). A drug-time interaction existed such that RPE scores were significantly lower with caffeine at the end of the trial ($p < .05$). There was no change in RPE over time with caffeine.

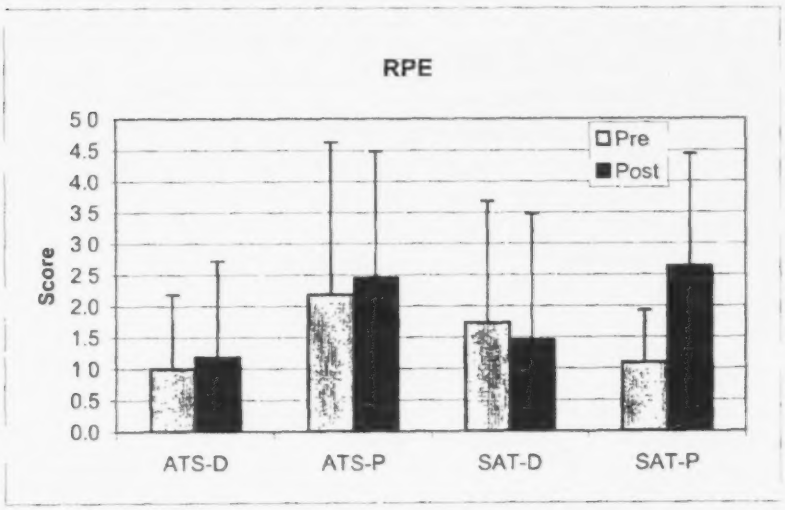

Figure 3. *Mean values ± SD of the RPE scores across all trial conditions, see text for significant effects*

Main effects for thermal sensation were found for all conditions of range, drug, and time. Subjects reported significantly lower TS scores (cooler) on the ATS range ($p < .01$), when taking the placebo ($p < .01$), and by the end of the session ($p < .05$). Ambient temperature in the SAT facility was controlled to 19 - 21°C, while the outdoor ATS

temperatures averaged 2.8 ± 3.8°C for the morning sessions and 10.8 ± 2.5°C for the afternoon sessions.

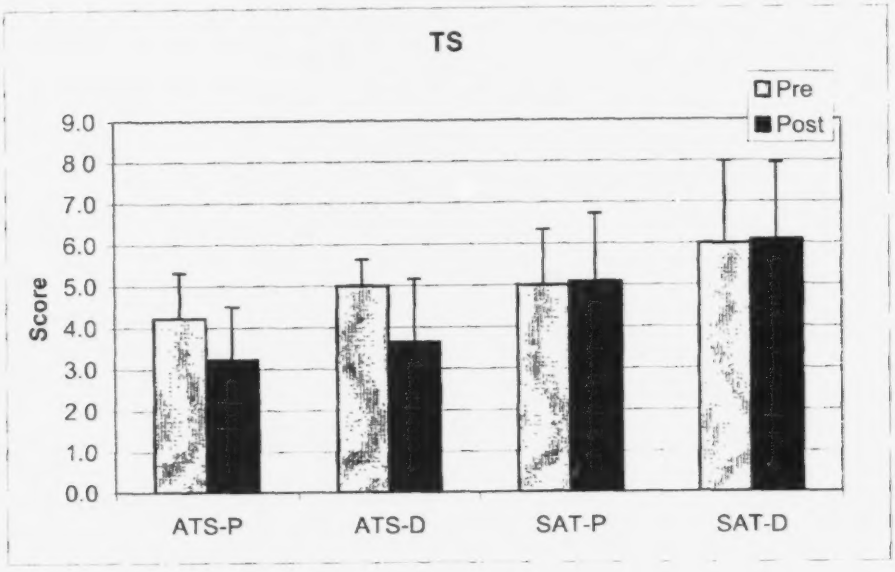

Figure 4. *Mean values ± SD of the TS scores across all trial conditions; see text for significant effects.*

Environmental Symptoms Questionnaire (ESQ)

Table 2 provides a summary of the four sub indices and individual questions where significant effects were found. Subjects reported being less cold ($p < .01$) and had a greater sense of well-being ($p < .05$) on the SAT. Well-being and muscle soreness were both adversely affected ($p < .05$ and $p < .01$, respectively) over the duration of an experimental session. Although there was a main effect of cold sensation increasing over time ($p < .01$), there was an interaction with range such that cold sensation increased by the end of the ATS while there was no difference across the SAT session ($p < .01$).

Caffeine interacted with time with respect to both sensations of tiredness and cold. Caffeine consumption decreased subjective sensations of tiredness, while tiredness increased in the placebo condition ($p < .05$). Subjects taking the placebo felt colder at the end of the session ($p < .05$).

Table 2. Pre and post session scores of the Environmental Symptoms Questionnaire (ESQ) where 0 = no symptoms and 5 = extreme, see text for significant effects

	ATS				SAT			
SUB INDEX	***D (Pre)***	***D (Post)***	***P (Pre)***	***P (Post)***	***D (Pre)***	***D (Post)***	***P (Pre)***	***P (Post)***
Well-Being	5 0±4 6	8 4±4 5	6 3± 5 0	6 5±4 4	5 1±4 3	6 8±4 0	6 1±4 7	5 9±4 3
Tiredness	2 0±2 8	1 1±2 5	1 5±1 6	2 2±2 4	1 8±2 1	1 1±1 9	1 9±1 7	3 1±2 3
Muscular Discomfort	0 6±1 2	5 2±4 3	1 1±1 3	5 9±6 1	1 4±1 8	4 3±5 1	0 9±1 9	5 1±4 7
Cold	0 5±1 2	6 8±6 5	0 1±0 3	9 8±5 3	0 2±0 4	0 6±1 2	0 1±0 3	1 2±2 2
QUESTION								
My hands, arms or shoulders ached	0 2±0 4	1 6±1 3	0 3±0 5	1 8±1 3	0 6±0 9	1 4±1 4	0 3±0 9	1 8±1 5
My back ached	0 1±0 3	1 1±1 0	0 3±0 5	1 1±1 4	0 2±0 4	1 3±1 3	0 1±0 3	1 3±1 4
My hand were cold	0.2±0.6	1 5±1 8	0 0±0 0	2 4±1 3	0 1±0 3	0 1±0 3	0 0±0 0	0 5±1 0
My feet were cold	0 0±0 0	1 8±1 9	0 0±0 0	2 4±1 2	0 0±0 0	0 2±0 4	0 0±0 0	0 4±0 8
I felt chilly	0 4±0 8	1 5±1 6	0 0±0 0	2 1±1 6	0 1±0 3	0 0±0 0	0 1±0 3	0 2±0 4
My vision was blurry	0 1±0 3	0 2±0 4	0 0±0 0	0 3±0 6	0 0±0 0	1 4±1 6	0 0±0 0	0 8±1 3
I was thirsty	0 6±1 0	0.5±0 8	0 3±0 6	0 8±1 2	1 2±1 4	1 1±1 3	0 2±0 4	0 6±1 0
I felt tired	1 1±1 2	0 6±1 3	0 8±0 8	1 2±1 2	0 8±0 9	0 5±0 9	0 8±0 9	1 4±1 0
I felt wide awake	1 1±1 7	2 9±2 1	1 6±1 8	1 8±1 8	1 2±1 7	1 6±1 7	1 1±1 8	1 7±1 7
My concentration was off	0 4±0 7	1 2±1 5	0 2±0 4	1 1±1 1	0 2±0 6	1 2±1 1	0 2±0 4	0 8±0 9
I felt restless	0 2±0 6	1 5±1 8	0 1±0 3	0.8±1.3	0 4±1 0	1 3±1 7	0 0±0 0	0 5±1 0
I was bored	0 2±0 6	1 0±1 4	0 5±0 9	1 1±1 6	0 4±0 9	1 2±1 5	0 3±0 6	1 6±1 5
I was hungry	0 8±1 1	1 6±1 7	0.7±1 0	1 6±1 4	0 5±0 8	1 1±1 1	0 5±0 9	1 2±0 9

Individual ESQ questions showing significant effects were centered on subjective sensations of muscular soreness, cold, and concentration/boredom. As would be expected, bodily aches, concentration, blurred vision, restlessness, boredom, and hunger worsened with time. Cold hands and feet, and chill were more prevalent on the ATS, and increased with time, while vision was blurrier on the SAT and worsened with time.

Caffeine consumption resulted in the subject's hands feeling less cold with time, than in the placebo sessions ($p < .05$). A greater sensation of thirst was also noted with caffeine ($p < .05$), and this effect interacted with time such that thirst was higher prior to the start of the session, but did not increase with time ($p < .05$). The placebo condition resulted in lower, initial thirst scores, which increased to the same level of the caffeine condition post session ($p < .05$). Caffeine and time interacted such that tiredness tended to increase with P and decrease with D ($p < .01$). By sessions end, tiredness was significantly less in the D condition.

Subjects felt colder in the hands, feet, and body on the ATS vs. SAT, and their hands also felt colder with time. Complaint of blurred vision was greater in the SAT ($p < .05$) and worsened with time ($p < .05$). Wakefulness was lower on the SAT ($p < .05$) and degraded with time ($p < .05$).

TLX

The Task Load Index (TLX) was completed at the end of each experimental session. The only significant effect noted was a decrease in perceived performance on the SAT (5.5 ± 2.5 and 5.5 ± 2.8 during D and P, respectively) as compared to the ATS (4.0 ± 2.2 and 4.4 ± 2.2) ($p < .05$).

Target detection and marksmanship

Friend/Foe discrimination

Due to time constraints and technical limitations, engagement times and marksmanship were only obtainable for the ATS, and are reported elsewhere [3]. The discriminatory index (d') showed no difference across all conditions, and indicated that the subjects were able to reasonably discriminate between friendly and foe targets. However, when comparing the appropriate and inappropriate responses [i.e., engaging foe targets (25 out of 40) or holding fire on friendly targets for a perfect score of 40], the results revealed a range effect such that more inappropriate responses occurred on the SAT ($p < .05$). Post-hoc analysis also revealed that less correct identifications were made during the first FF sequence ($p < .05$), and there was no difference in the subsequent sequences.

While the number of shots taken were not affected by the experimental condition, the number of targets hit was greater on the ATS ($p < .01$), as shown in Figure 5. The

ratio of targets hit to number of shots taken was also higher on the ATS ($p < .01$). This difference was considerable with only 54% of SAT shots finding their mark vs. 87% of ATS shots. ATS shooting performance remained unchanged across the four sequences, while SAT performance was worse during the first sequence compared to the following three ($p < .01$).

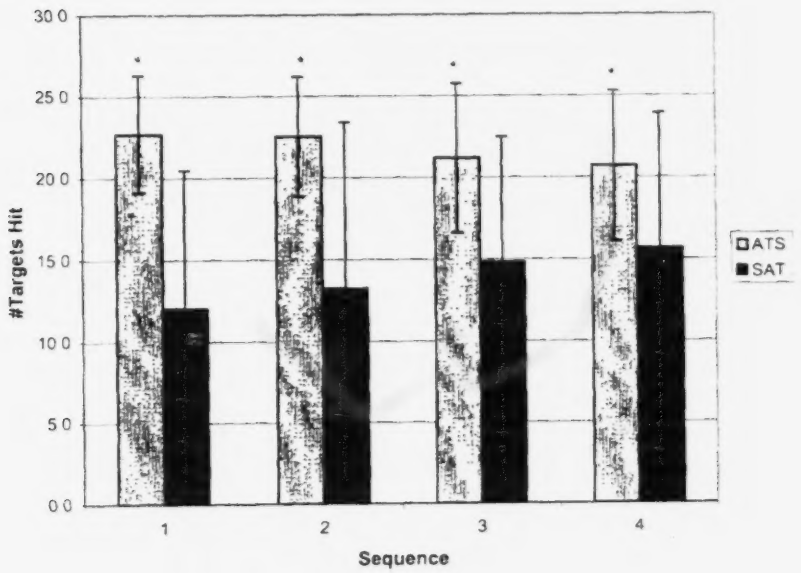

Figure 5. *Comparison of number of targets hit in each FF sequence., * indicates a significant effect of range (p < 01) and a range x time interaction (p < 01)*

Vigilance

Engagement time was only available for the ATS and are reported elsewhere [3]. More targets where hit on the ATS range ($p < .01$) and fewer shots were fired in the SAT ($p < .01$).

The hit-shot ratio was also less on the SAT ($p < .01$), as shown in

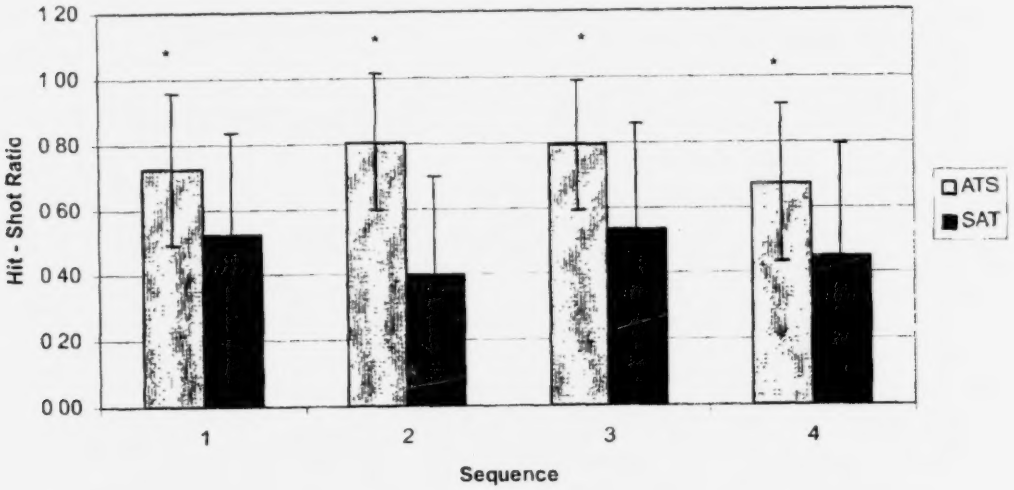

Figure 6, and subjects tended to take a greater number of shots in the caffeine condition as compared to placebo ($p < .01$).

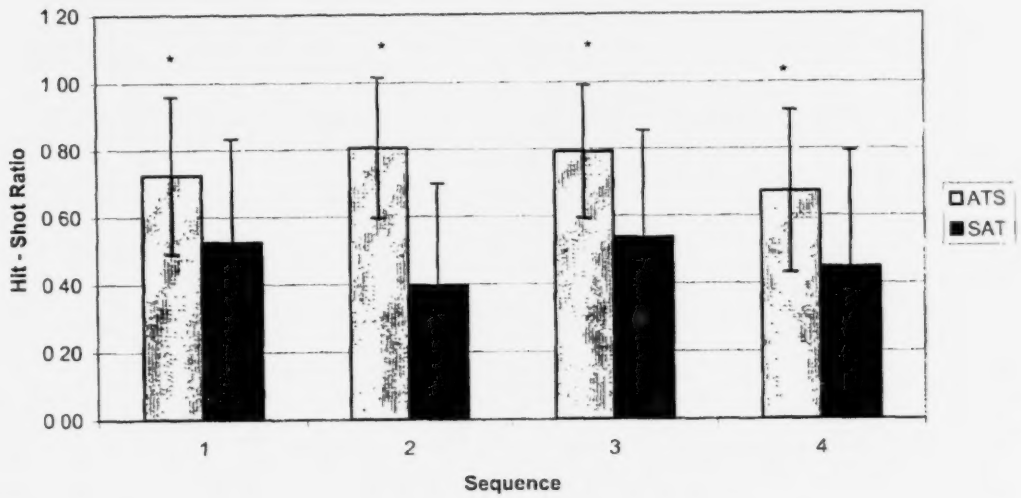

Figure 6. *Hit - Shot ratio comparison of live (ATS) and simulated (SAT) firing across all VIG sequences; * indicates a significant effect.*

Marksmanship data generated in the SAT were generally deemed to be of poor quality and susceptible to technological deficiencies. It was therefore necessary to filter the data by accepting shots within 10 cm of the target for analyses. These deficiencies and the rationale for the data criterion are described in greater detail in the discussion section of this report. The amount of useable SAT marksmanship data was reduced to 4 subjects.

Subsequent analyses of the shot metrics indicated that precision and accuracy were different on the two ranges. Where there was a main range effect, the scores indicated poorer performance on the SAT (Table 3). Performance tended to decline with time, although this was not statistically significant.

Table 3. *Marksmanship during vigilance on the SAT resulting in a main effect of range ($p < .05$) All values are in cm with the exception of AREA which is in cm^2.*

	ATS				SAT			
	VIG 1	***VIG 2***	***VIG 3***	***VIG 4***	***VIG 1***	***VIG 2***	***VIG 3***	***VIG 4***
CE	22 04±10.01	21 34±11 45	20 06±11 53	20±9 63	25 63±14 58	31 07±13 72	30 61±13 59	24 19±15 12
SE	26 8±9 5	25 96±8 83	24 22±9 76	25 2±9 36	28 08±15 05	26 44±18 28	30 84±15 51	26 22±15 17
MR	14 12±5 09	12 74±4 2	12 6±4 29	14 75±5 17	14 67±7 95	10 44±8 12	13 1±7 16	13 45±8 57
AREA	597 79±352 4	451 54±247 04	619 01±300 94	773 38±460 86	253 67±238 61	183 34±172 45	306 37±161 88	326 23±174 44
DIA	59 17±19 61	55 86±19 68	52 42±18 37	59 85±18 8	55 18±33 02	40 05±30 85	47 99±27 62	49 24±35 19

Range and caffeine interacted significantly with DIA ($p < .05$) and MR ($p < .01$). Caffeine did not exert any influence on these marksmanship measures in the ATS condition, but tended to decrease performance in the SAT (Figure 7).

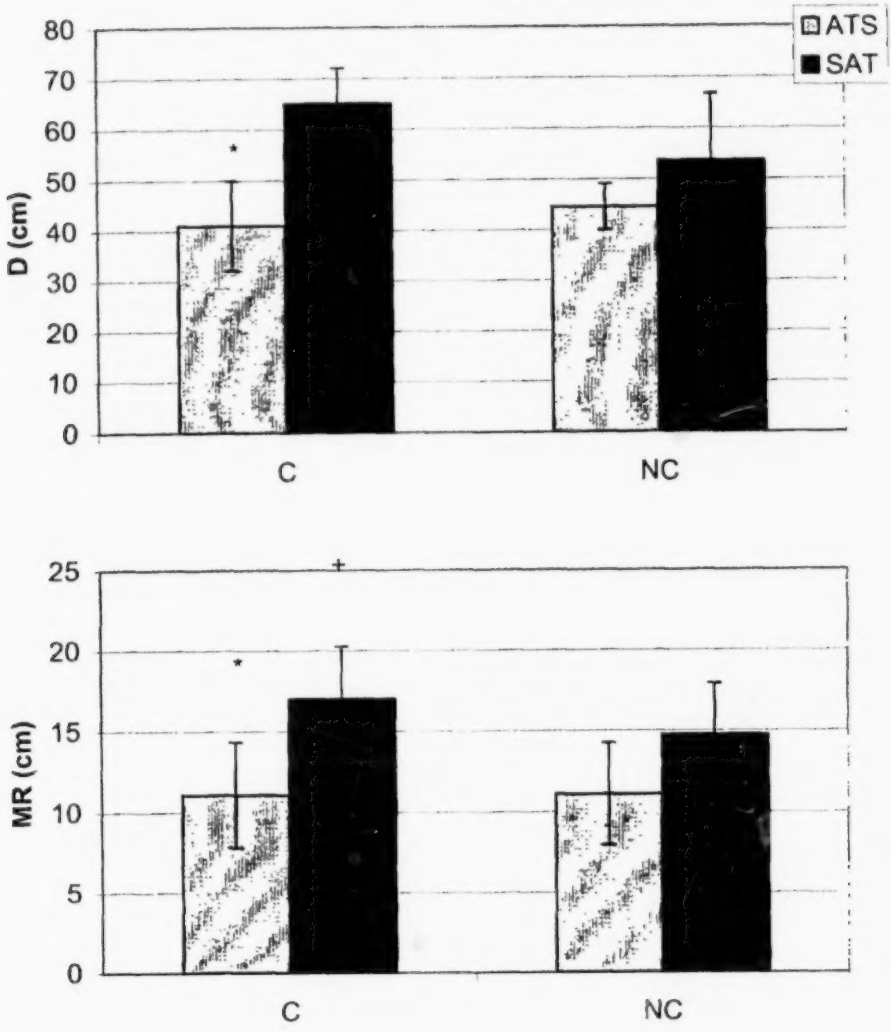

Figure 7. *Range (ATS vs SAT) and placebo (P) vs drug (D) interaction in DIA (top) and MR (bottom), * denotes range effects; * denotes caffeine effect (p < .05).*

Discussion

The results of this study indicate that marksmanship using the FATS IV SAT was markedly different than live fire. In almost every performance measure analyzed, shooting in the simulator produced poorer results, despite the limited validation of simulator use for training purposes. Although the validation studies were able to derive simple correlations between live and simulated shooting scores on standardized firing relays, the dependent variables used to test the robustness of their conclusions were restricted to the skill level of the marksmen [2; 19] and level of difficulty of the relay [16]. In addition, the correlations, while statistically significant, explained only a small portion of the performance variability. These validation studies suggest that there may be a limit to the scope of conformity of performance between the live and simulated environments. While a main effect of range type was most common in our study, there were many instances where changes in performance in the simulator due to the effect of time or caffeine did not concur with the live fire.

The most notable difference between the two ranges was the ambient surrounding. During the several days of the study, outdoor temperatures on the ATS ranged from approximately -3 to 14°C. Within each trial, there were daily variations in wind speed, cloud cover, and sun angle. Moreover, the final day of testing was confounded by an unexpected snowfall. In contrast, the simulated fire was held in a relatively constant environment where the temperature and lighting were controlled. The effects of these weather variants were evident in the ratings of TS and ESQ.

Not surprisingly, subjects felt cooler on the live range with TS cold sensation increasing over the duration of a session. This may partially account for the better live fire performance, as Tikuisis et al. [18] reported improved marksmanship with cold strain, probably due to an increase in arousal. The cold sensation index of the ESQ mirrored the TS results with the added significant range x time interaction indicating no change in cold sensation with time in the simulator. However, cold sensation was attenuated with caffeine ingestion. Although no physiological measurements were taken to determine whether body temperatures increased, recent investigations do not support a thermoregulatory effect [18], suggesting that only the perception of cold was affected.

All rifle firing was done from the supported prone position. Over the duration of a session, subjects complained of physical and psychological fatigue. Muscle, back and shoulder aches, general physical well being, concentration, hunger, and boredom were all adversely affected. As marksmanship tended to degrade with time, it is likely that postural and psychological fatigue were contributing factors. As the supported prone position facilitates the greatest firing accuracy due to minimal rifle movement and postural sway, as compared to a sitting, kneeling, or standing posture [20], it is possible that marksmanship degradation due to fatigue would be greater in a less stable posture. Occasional stretch breaks or changes in posture might be considered when operational conditions permit. Caffeine appeared to provide some relief to the sensation of tiredness and perceived exertion over time. This is not surprising given its well-documented effects as a stimulant [4]. Thirst was also greater with caffeine consumption, which concurs with Smit and Rogers [17] who reported such an increase in low habitual users.

In the simulator, subjects indicated a higher sense of well-being and decreased wakefulness. These finding are not surprising given that the facility housing the simulator was controlled at a comfortable ambient temperature and invariant to outdoor conditions (eg., wind, cloud, etc.). Paradoxically, the comfortable conditions may have contributed to the subjects' poorer marksmanship during the vigilance task. Tikuisis et al. [18] found marksmanship improvements when subjects were exposed to a disturbing, but not debilitating level of hot or cold strain, as compared to a thermoneutral baseline condition. It was postulated that the thermal strain caused a beneficial arousal such that the subjects were better able to focus on the shooting task. Additionally, light levels in the simulator were kept low to facilitate viewing of the projected display and correct laser detection. Being devoid of the natural stimulation of the sights and sounds of an outdoor environment, and lying on a padded firing platform, the subjects often struggled to remain alert. A possible recommendation to counter these lulling effects would be to add ambient, range, and/or battlefield sounds, to ensure adequate room ventilation, and to avoid an overly comfortable platform.

Subjects also complained that their vision was blurry in the SAT. Although light levels were not measured in this study, a combination of low room illumination and screen luminance, limited image resolution, and focusing difficulties with the red, blue, and green light channels of the projection system contributed to this impaired visual acuity. Since the completion of this study, upgrades to the SAT have included the addition of a single lens projection system that appears to provide for much greater luminance and clarity. A second factor contributing to the poor image quality was the use of a standard C79 scope. While the targets were situated at a simulated distance of 200 m, the actual screen upon which targets were displayed was only 8 m from the subject, well within the focal length of the scope. A SAT-specific scope, with appropriate focal length, has since been made available and should improve visibility in future studies.

Decreased wakefulness and visual acuity may also be responsible for the subjects' perception of lower performance on the SAT. These findings were similar to those reported by Gula [5] in addition to comments regarding the obtrusive placement of the compressed air hose on the hand guard. Numerous weapons stoppages, as well as the system failing to register the weapon's zeroing information, led to a high degree of frustration. The net result of these irritants decreased the subject's confidence in the system and may have negatively affected their motivation and performance.

Analysis of d′ (discriminatory index) indicated that the subjects were able to adequately discriminate between the friendly and foe targets, although the number of correct identifications in the SAT were less than on the live range. Again, some subjects remarked that, due to the poor resolution of the video display, the friend/foe markings on the targets appeared pixilated and more difficult to distinguish than on the live range. A decrease in resolution affects the texture gradient, causing SAT targets to appear farther away. This might partially explain the poor shooting performance on the SAT and the findings of Gula [5] who noted SAT performance being better than live at 100 m, but significantly degraded at 200 m. Additional perceptual cues such as relative size, cast shadows, and other pictorial features may have been inappropriate or missing in the authored engagements resulting in errors of target distance judgement. As the first FF sequence resulted in the poorest performance, it is possible that a period of adjustment and familiarization was required before

the subjects could adequately engage the targets, despite being practiced during the pre-trial familarization session.

In addition, fewer SAT targets were engaged in the placebo condition and in the latter sequences. By extension, this concurs with the findings of Johnson and Murello [13], who reported that approximately 10% of all shots were fired after the target had disappeared after 6 s of exposure. It is possible that the shorter 4 s target exposure time in our study posed a greater challenge to the subjects' vigilance and target engagement, thereby allowing caffeine to exert its stimulatory effect.

Vigilance performance was also poorer on the SAT. Unfortunately, the poor quality of data restricted complete and reliable analyses to 4 subjects. It was felt that such an analysis could be justified, as the effects of any system irregularities would be minimized. This re-analysis had little effect on the overall interpretation of marksmanship scores during the vigilance task. SAT scores were still substantially poorer than ATS scores, and marksmanship still degraded with time.

It was discovered, after the completion of the study, that the then current version of the SAT software occasionally failed to register the zeroing information of the weapons (FATS INC. have since verified the existence of this deficiency). This helps explain the biased or erratic shooting displayed in certain sequences. An example of this is shown in Figure 8, which demonstrates a distinct bias in a subject's shooting between two contiguous sequences within a session. Gula [5] using the previous generation SAT (FATS III) system noted a similar phenomenon. In some circumstances, where initial weapon and sight alignment was good, and little zero adjustment was necessary, failure to register a weapon properly would be impossible to detect. A recent upgrade to the SAT software has addressed this issue and, if successful, should make the SAT a more reliable simulator.

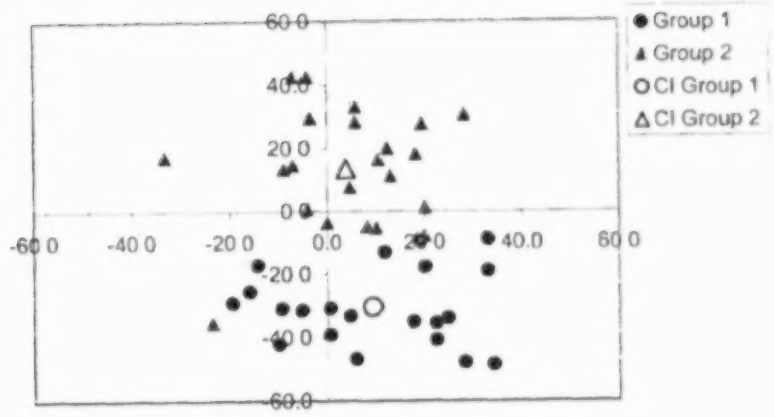

Figure 8. *Shot location and centre of impact (CI) of two contiguous vigilance sequences for one subject.*

A second possible explanation for the difference in scores is the range in which the SAT and ATS registered shot location. The ATS handled low shots differently from SAT, as low shots would either hit the ground and not be registered, or ricochet and tumble, hitting the target at a location higher than their original trajectory would have resulted. On the other hand, shots as low as 1 m below the target were registered by the SAT without being considered to have landed in front the target. The net result of these discrepancies would be a lower vertical bias to SAT marksmanship metrics.

Conclusion

A comparison of SAT and live-fire marksmanship, with and without caffeine consumption, in either friend/foe or vigilance engagements revealed substantial differences in subjective perceptions of the environment and shooting performance. Many of these differences can be attributed to the conditions of the ranges and the quality of the SAT software and projection system. Despite an attempt to create similar environments and target engagements, the results of this study indicate that performance on the SAT was poorer than live fire. Differences in weather/climate control conditions, arousal, visual acuity, and system reliability affected not only shooting performance, but on how caffeine influenced target detection and marksmanship on each range. Unfortunately, the colder condition on the ATS range interacted with the subjects' performance and disallowed a fair validation of the SAT as a surrogate research platform for studies involving the effects of stressors/aids on TD&M. However, had the ambient conditions been similar between the two ranges, it is doubtful that results on the present SAT would have matched those on the ATS due to the technical limitations of the SAT.

Measurements of shot location on the SAT were deemed to be of poor quality and required considerable care when the results were analyzed. Extraction of the data was a tedious and time-consuming process, which disrupted the continuity of the experiment and created undesirable downtime for the subjects. They eventually became frustrated and disenchanted by the system's cumbersome operation and unreliability, which undoubtedly contributed further to their poor performance. Since this study has been completed, a new generation of SAT software and hardware has been made available. Several of the most significant issues, such as visual acuity, weapon function, and zeroing registration have been addressed. With these system improvements, coupled with improved data reporting capabilities and a greater effort to create a SAT facility that provides a similar level of arousal as a live range, the SAT should realize its potential of providing a cost-effective and flexible marksman research platform.

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22.

List of symbols/abbreviations/acronyms/initialisms

DND	Department of National Defence
SAT	Small Arms Trainer
ATS	Automated Targetry System
FF	Friend-Foe
VIG	Vigilance
P	Placebo
D	Drug (caffeine)
CE	Constant Error
SE	Standard Error
MR	Mean Radius
DIA	Diameter

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(U) A comparison of target detection and rifle marksmanship during live and simulator firing with and without caffeine consumption

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14 ABSTRACT

(U) This study investigated the effects of caffeine ingestion on target detection and rifle marksmanship, and compared performance between live and simulated firing. Thirteen male, rifle-trained Canadian Forces reservists performed a total of 1 familiarization and 4 experimental sessions over an 8-day period. Familiarization was conducted on the small arms trainer (SAT), while the 4 experimental sessions were evenly distributed between 2 sessions each of SAT and live shooting, once with and once without caffeine. Each session comprised 8 shooting sequences 1 h following the ingestion of 300 mg of caffeine or placebo, and lasted approximately 2.5 h. Shooting sequences included both friend-foe (FF) and vigilance (V) tasks and were performed in the following order: two FF engagements (4 min each), four V engagements (30 min each), and two FF engagements (4 min each). Performance measures during the shooting session included target discrimination, and marksmanship accuracy and precision. Assessments of thermal comfort and tiredness preceded and followed the shooting session. The Environmental Symptoms Questionnaire was administered pre- and post-shooting, while the Task Load Index was administered post-shooting only. Blood was sampled immediately prior to the beginning of the shooting session to confirm plasma caffeine levels. Caffeine ingestion resulted in lower subjective sensations of effort and an increased initial level of thirst. Subjects also reported feeling colder during live fire and experienced blurred vision and lower levels of wakefulness on the SAT. Marksmanship performance was substantially poorer in the SAT and adversely affected by caffeine. No caffeine induced performance decrements were noted during live fire, but caffeine resulted in a greater number of shots taken on both ranges. Although consistencies between live and SAT performance were not achieved, recommendations on rectifying several key technological constraints are proposed that should help realise the research potential of the SAT.

(U) Cette étude comparait les effets de l'ingestion de caféine sur la détection des cibles et l'adresse au tir, dans le cadre de tirs réels et simulés. Treize réservistes des Forces canadiennes (FC), de sexe masculin et entraînés au tir, se sont soumis à 1 séance de familiarisation ainsi qu'à 4 séances expérimentales, sur une période de 8 jours. La séance de familiarisation a eu lieu sur le simulateur d'entraînement au tir aux armes légères (SAT), tandis que les 4 séances expérimentales ont été réparties au hasard et également entre 2 séances sur le SAT et les séances de tir réel sur le système de ciblerie automatique (SCA). Chaque séance comportait 8 séquences de tir, exécutées une heure après l'ingestion de 300 g de caféine ou d'un placebo. Les séquences de tir comprenaient des tâches d'identification ami-ennemi (IFF) et des tâches de vigilance (V), et étaient exécutées dans l'ordre suivant : deux engagements IFF (4 minutes chacun), quatre engagements V (30 minutes chacun), et deux engagements IFF (4 minutes chacun). La séance de tir durait environ 2,5 heures, pour les essais avec caféine comme pour ceux avec placebo. Les indicateurs de performance utilisés durant les séances de tir étaient l'identification ami-ennemi et l'exactitude et la précision du tir. Ces séances de tir étaient précédées et suivies par une évaluation du confort thermique et de la fatigue ainsi que par l'administration du questionnaire sur les symptômes liés à l'environnement (Environmental Symptoms Questionnaire, ESQ); on calculait également l'indice de charge de travail (Task Load Index) à la fin des séances. Des échantillons de sang étaient prélevés immédiatement avant le début de la séance de tir pour déterminer les teneurs plasmatiques en caféine. La présence de caféine s'est traduite par une diminution des sensations d'effort subjectives et une hausse du degré de soif initial. Les sujets ont déclaré avoir eu plus froid lors des séances SCA, et avoir eu la vue brouillée et un niveau d'éveil moindre lors des séances SAT. La performance au tir a été nettement inférieure dans les séances SAT et a été perturbée par la caféine. On n'a observé aucune diminution de performance induite par la caféine dans les séances SCA, mais la présence de la substance s'est traduire par une augmentation du nombre de coups tirés dans les deux situations (SAT et SCA). Les résultats de cette étude indiquent que, malgré le manque d'uniformité entre les tirs réels et simulés, la correction de plusieurs problèmes techniques majeurs permettrait de réaliser le plein potentiel du SAT pour la recherche.

15 KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) Marksmanship; Caffeine; Small Arms Trainer; SAT; Automated Targetry System; ATS